Introduction to Green Infrastructure

There are many definitions of green infrastructure which have circulated in literature and dialogue in recent years. Many of these definitions focus on the varying benefits or uses of green infrastructure practices, such as enhancing biodiversity or filtrating polluted runoff. While green infrastructure does provide a multitude of benefits, it is important to define the primary goal of green infrastructure practices to help design plans which optimize their use (Matsler et al., 2021).

Our definition is simply stated as green infrastructure for urban stormwater management. Similar to the EPA, which defined green infrastructure as a stormwater management technique that can provide a variety of other benefits to a community, we believe that it is “a cost-effective, resilient approach to managing wet weather impacts that provides many community benefits” (Matsler et al., 2021).

Green infrastructure can also be defined by the scale at which it is implemented. Many organizations, such as ESRI, define green infrastructure as large areas of green space which are planned on a regional scale. Instead, however, we chose to focus on smaller practices which can be implemented in an urban environment at site and neighborhood-level scales. In our work we have 11 unique green infrastructure practices, including two types of green roofs, rain barrels,

three types of permeable pavements, stormwater trees, and the infiltrating practices of bioswales, rain gardens, native landscaping, and constructed wetlands.

Here are the definitions of each practice, along with their estimated water capture and cost and important maintenance and suitability considerations. The water capture and costs (total construction and annual maintenance costs) were accumulated and averaged from a variety of online sources (Wisconsin Sea Grant, 2020).

Green Roofs

Green roofs are an area of a roof or deck covered in some form of vegetation, ranging from grass to shrubs, with the goal of reducing runoff and creating a cooling effect by insulating the building. Intensive and extensive green roofs vary in the depth of the substrate and the types of vegetation.

Maintenance Considerations: Regular maintenance is required for green roofs, including weed removal, replacement of dead plants, fertilizer application, and supplemental watering when necessary (Operation and maintenance (O&M) of green roofs). The annual average maintenance cost is estimated at $4,120 (Detwiler).
Suitability Criteria: Green roofs can only be placed on buildings that have a slope of up to 30% (Guidance for Federal Land Management, 2010). The roof must be constructed of a material other than wood and must be able to support the weight of the saturated vegetation (Guidance for Federal Land Management, 2010). Furthermore, the roof surface must receive adequate sunlight (not shaded by other tall buildings).

Intensive Green Roofs
Have a greater depth of planting medium and soils (>6 inches) than extensive green roofs. Similar to a garden, they are suitable for larger plant species, such as trees and shrubs (What's the Difference). Used commonly for large, commercial buildings (Admin).

Water Capture: 0.197 gal/SF*
Cost: $40.08/SF
Maintenance Cost: $0.75 SF/year

Extensive Green Roofs
Have a planting medium that is shallower than intensive roofs (1.6 - 6 inches deep). Common plants include grasses, succulents, and other ground cover species that are drought tolerant because extensive green roofs tend to dry out quickly (What's the Difference). Used commonly for single-family and other residential buildings and are simpler to install then intensive roofs because they are often added to existing roofs and require less maintenance (Admin).

Water Capture: 0.152 gal/SF*
Cost: $40.08/SF
Maintenance Cost: $0.75 SF/year

*The amount of water that a green roof captures during a ½-inch rain event.

Rain Barrels

Rain barrels are containers of varying sizes which are used to capture rainwater from roofs and downspouts, allowing the water to be reused onsite for gardens or lawns.

Maintenance Considerations: Rain barrels only function in the warm months and must be winterized yearly in Wisconsin to prevent water from freezing within and damaging the device.
Suitability Criteria: Rain barrels must be placed on flat, even ground in shaded areas to prevent the growth of algae. Furthermore, the available space around a building must be considered for the placement of rain barrels.

Water Capture: 0.32 gal/SF
Cost: $1/SF
Maintenance Cost: $0 (but need to be replaced about every 10 years)

Permeable Pavement

Permeable pavement is pavement which allows water to infiltrate into the ground below, such as through manufactured permeable pavements or by leaving gaps in the pavement blocks. There are a wide range of porous pavement options.

Maintenance Considerations: Permeable pavement requires periodic vacuuming (about twice per year) to remove sediments and debris trapped in the pavement. The use of salt and sand should be limited on sites with permeable pavement and nearby landscaping should be monitored to prevent soil from washing onto the surface (Operation and maintenance of permeable pavement). The annual average maintenance cost is estimated at $247 (Detwiler).
Suitability Criteria: Permeable pavements are best constructed in low-volume areas, such as residential roads and driveways, sidewalks, parking lots, and patios (Ellis et al., 2014). In contrast, highways and other busy and high-speed roads may not be a suitable location for permeable pavement because of the high levels of traffic that these areas receive and the risk of spills and contaminants. Permeable pavement can only be placed on ground that has a slope of less than 10%.

Pervious concrete
A type of concrete that is manufactured with void space to allow water to infiltrate through the pavement surface and into the ground (Permeable Pavement).

Water Capture: 0.185 gal/SF*
Cost: $7.72/SF
Maintenance Cost: $0.14 SF/year

Permeable interlocking concrete pavement
Concrete blocks that are laid to form different patterns, leaving gaps between the blocks for water to infiltrate which is filled with gravel, soil or grass (Permeable Pavement).

Water Capture: 0.102 gal/SF*
Cost: $9.05/SF
Maintenance Cost: $0.14 SF/year

Porous asphalt
A type of asphalt manufactured with less fine stone aggregate to allow for void space and the infiltration of water through the asphalt surface (Permeable Pavement).

Water Capture: 0.176 gal/SF*
Cost: $5.32/SF
Maintenance Cost: $0.14 SF/year

*The amount of water that permeable pavement options capture during a ½-inch rain event.

Stormwater Trees

Stormwater trees are small to large trees that contribute to stormwater capture through infiltration and evapotranspiration, while also providing many additional benefits to a community.

Maintenance Considerations: Stormwater trees require regular maintenance, such as watering for the first three years and continual weeding, mulching, pruning and trimming, along with pest and disease management as needed (Stormwater Trees: Technical Memorandum).
Suitability Criteria: Trees must be sited an adequate distance from other trees and tall buildings, so they receive enough sunlight. Careful attention should also be paid to the location of utilities, such as telephone lines, to avoid situations that require extensive pruning or the removal of trees as they grow (Guidance for Federal Land Management, 2010).

Water Capture: 50 gal/tree/event

Cost: $500/tree
Maintenance Cost: $31.01 tree/year

Bioswales

Bioswales are channels which are constructed with the aim of directing and slowing the flow of runoff and allowing for increased infiltration. Bioswales are commonly constructed beside streets, sidewalks, and parking lots and typically contain rocks and plants.

Maintenance Considerations: Bioswales do not require extensive maintenance. However, they must be inspected annually or after major storm events to ensure vegetation is intact and there is no sediment buildup (Bioswales – Naturally Resilient Communities). Vegetation may require supplemental irrigation in the first 2-3 years after planting or during drought (Guidance for Federal Land Management, 2010). The annual average maintenance cost is estimated at $313 (Detwiler).
Suitability Criteria: Bioswales must be located on ground that has a slope of less than 20% (Guidance for Federal Land Management, 2010). Typical areas that are suitable for bioswales include right of ways, medium strips, curb strips, parking lots, and traffic islands. They should not be located in areas with high levels of groundwater contamination or sediment loading (Guidance for Federal Land Management, 2010). Infiltration of bioswales will be impeded by shallow bedrock depth and high-water tables (Guidance for Federal Land Management, 2010). Well-draining soils are recommended to allow for rapid infiltration and high levels of stormwater retention (Guidance for Federal Land Management, 2010).

Water Capture: 7.48 gal/SF
Cost: $16/SF
Maintenance Cost: $0.31 SF/year

Rain Gardens

Rain gardens are small, landscaped areas often with native plants which are used for capturing and filtering runoff during rainfall events through evapotranspiration and infiltration.

Maintenance Considerations: Rain gardens do not require extensive maintenance. However, weeds and dead debris should be removed a few times a year (Rain Gardens). The annual average maintenance cost is estimated at $72 (Detwiler).
Suitability Criteria: Rain gardens should be sited on relatively flat sites and adequately distanced from underground facilities which the rain garden may disrupt. For example, they should be placed at least 10 feet away from buildings with basements and 15 feet away from septic tanks, water wells, or septic drain fields. The proximity to busy roads must also be considered in the

placement of rain gardens because the use of salt on roads in the winter can harm the plants grown in this type of green infrastructure. Salt tolerant plants may be chosen for areas that receive runoff from heavily salted roads. Hydrologic soil types A and B are ideal for infiltrating green infrastructure practices such as rain gardens (Guidance for Federal Land Management, 2010).

Water Capture: 5.37 gal/SF
Cost: $13/SF
Maintenance Cost: $0.59 SF/year

Native Landscaping

Native landscaping is similar to rain gardens in that they are small, landscaped areas of native plants. Using native species has the added benefit of providing habitat for wildlife and insects.

Maintenance Considerations: Similar to rain gardens, native plantings must occasionally be weeded, and residual debris removed.
Suitability Criteria: Native plantings have similar suitability requirements as rain gardens.

Water Capture: 1.5 gal/SF
Cost: $1/SF
Maintenance Cost: $0.05 SF/year

Constructed Wetlands

Constructed wetlands are areas which can be flooded and remain saturated with water for a long period of time, such as a shallow marsh. They are typically located between a body of water and dryland as a buffer zone between the two distinct areas and planted with vegetation that treats runoff.

Maintenance Considerations: Wetlands require some annual maintenance, such as removing invasive plants and debris (Stormwater Maintenance Fact Sheet). The annual average maintenance cost is estimated at $752 (Detwiler).
Suitability Criteria: Constructed wetlands are typically located on large areas between water and land, as they are considered a transition point between these two landscapes (Guidance for Federal Land Management, 2010). They should be placed on low, flat sites with slopes less than 15% (EPA). However, a gentle slope is beneficial because it allows water to flow through the wetland using gravity (EPA). A constructed wetland should also be above the water table and outside of a floodplain. Similar to bioswales, they should not be placed in areas with high levels of groundwater contamination (Guidance for Federal Land Management, 2010). They should

always be situated at least 10 feet from property lines (Ellis et al., 2014). In order to maintain a permanent pool, the preferred soil type for this green infrastructure practice is slow draining soils, such as those in the Hydrologic Soil Group C or D (Ellis et al., 2014).

Water Capture: 14.36 gal/SF
Cost: $2/SF
Maintenance Cost: $0.04 SF/year

Summary Tables

Green infrastructure capture/infiltration capacity for ½-inch rain event

Polygon Green Infrastructure Practice	Design Field 1: Stormwater Managed (gallons/SF)**	Design Field 2: Total cost ($/SF)	Design Field 3: Annual maintenance cost ($/SF/year)
Bioswale	7.480	15.98	0.31
Constructed Wetland	14.360	1.97	0.04
Native Landscaping	1.500	0.1	0.05
Rain Garden	5.370	13.02	0.59
Extensive Green Roof	0.152	17.69	0.75
Intensive Green Roof	0.197	40.08	0.75
Permeable Interlocking Concrete Pavement	0.102	9.05	0.14
Pervious Concrete	0.185	7.72	0.14
Porous Asphalt	0.176	5.32	0.14
Roof Managed by Rain Barrels	-0.000008	0.34	0
Point Green Infrastructure Practice	**Design Field 1: Water abstracted by tree canopy (gallons/tree)**	**Design Field 2: Total cost ($/tree)**	**Design Field 3: Annual maintenance cost ($/tree/year)**
Stormwater Trees	50	269	36

* Design Field 1 for bioswale, constructed wetland, native landscaping, rain gardens and stormwater trees averaged from multiple sources for water capture capacity; Design Field 1 for all other practices were calculated using the curve number (CN) runoff method and averaged CN for the practices from multiple sources.

Green infrastructure capture/infiltration capacity for 2-inch rain event

Polygon Green Infrastructure Practice	Design Field 1: Stormwater managed (gallons/SF)*	Design Field 2: Total cost ($/SF)	Design Field 3: Annual maintenance cost ($/year)
Bioswale	7.48	15.98	0.31
Constructed Wetland	14.36	1.97	0.04
Native Landscaping	1.5	0.10	0.05
Rain Garden	5.37	13.02	0.59
Extensive Green Roof	0.37	17.69	0.75
Intensive Green Roof	0.71	40.08	0.75
Permeable Interlocking Concrete Pavement	1.09	9.05	0.14
Pervious Concrete	0.92	7.72	0.14
Porous Asphalt	0.96	5.32	0.14
Roof Managed by Rain Barrels	1.1	0.34	0
Point Green Infrastructure Practice	**Design Field 1: Water abstracted by tree canopy (gallons/tree)**	**Design Field 2: Total cost ($/tree)**	**Design Field 3: Annual maintenance cost ($/tree)**
Stormwater Trees	50	269	36

* Design Field 1 for bioswale, constructed wetland, native landscaping, rain gardens and stormwater trees averaged from multiple sources for water capture capacity; Design Field 1 for all other practices were calculated using the curve number (CN) runoff method and averaged CN for the practices from multiple sources.

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